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ENVIRONMENTAL IMPACTS OF NITROGEN USE IN AGRICULTURE

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Nitrogen is a common element in nature. Approximately 78% of the earth's atmosphere consists of nitrogen gas (N_2). As nitrogen naturally cycles through the air, soil and water, it undergoes various chemical and biological transformations. These reactions result in the formation of nitrogen-based compounds and molecules, which are essential for the growth of plants, animals and humans. Agricultural production is dependent, in part, on the cycling of nitrogen within the rural environment.

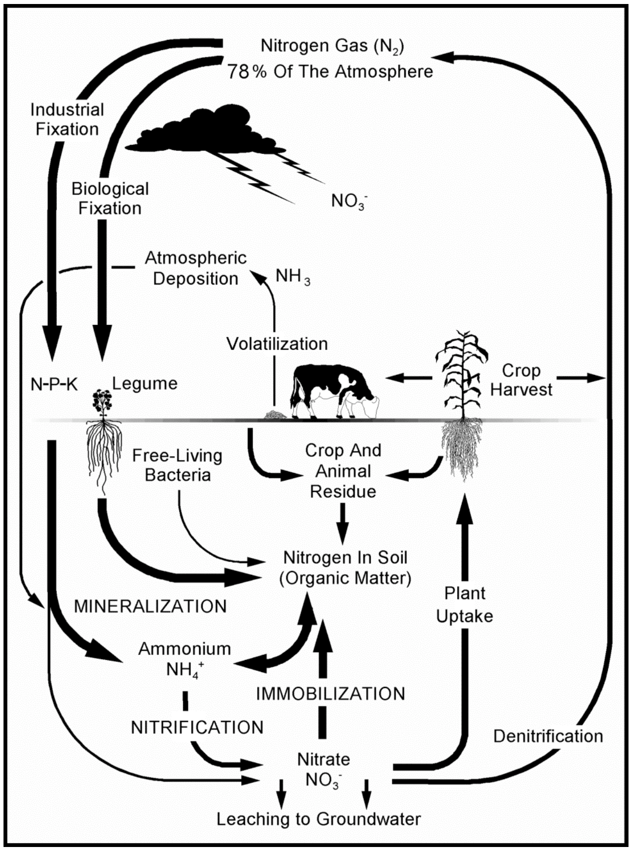

Figure 1: Nitrogen forms and pathways within an agricultural production system

Figure 1, left, illustrates the various forms and pathways that nitrogen (N) can take as it cycles through an agricultural production system. Before nitrogen can be used by plants, it must be converted into forms that are available to plants; this conversion is called mineralization. The plants take up these mineral forms through their root systems and form plant proteins and other organic forms of nitrogen. Livestock eat crops and produce manure, which is returned to the soil, adding organic and mineral forms of nitrogen to the soil, which can be used again by the next crop.

Ideally, it would be most economically and environmentally beneficial to keep all the nitrogen in this tight cycle for food production. In reality, however, some leakage occurs. Where there is too much nitrogen leakage, there can be environmental harm.

This Factsheet describes some of the impacts on the environment that can result when certain forms of agricultural nitrogen enter our surface water, groundwater and air, and identifies best management practices for minimizing nitrogen losses.

NITRATE

Nitrate (NO_3^-) is an extremely soluble form of nitrogen. It does not bind with the surfaces of clay minerals nor does it form insoluble compounds with other elements that it encounters when moving through the soil. Because nitrate is soluble, it can readily move with soil water toward plant roots to be taken up by them. However, if there is a large amount of water entering and passing through the soil root zone, NO_3^- can be carried by percolating water beyond the soil root zone. This downward and lateral movement through the rooting zone and possibly towards agricultural tile drainage systems is driven by water infiltrating from rainfall or a snow melt. This loss of nutrients (also called leaching) occurs at times of the year or at points in a field where the amount of rainfall or snow melt exceeds evapotranspiration and the soil is near its saturation capacity. Under such conditions, soil water moving downwards recharges groundwater or contributes to tile drain flow, carrying nitrate with it.

The Ontario Drinking Water Standards (ODWS) set 10 mg/L (10 parts per million) nitrate as nitrogen (NO_3-N) as the maximum allowable level for drinking water in Ontario. Studies published in scientific journals since the 1950s estimate that upwards of 15% of rural Ontario wells have nitrate levels greater than the ODWS of 10 mg/L NO_3-N. A study of farm water quality in the early 1990s came to a similar conclusion. Medical researchers concluded that a concentration of 10 mg/L in drinking water is appropriate to avoid blue-baby syndrome in human infants. Recent research suggests that consistently high levels of nitrate in surface waters can harm some forms of aquatic life, particularly amphibians. At this time, the Province is considering including nitrate in the Provincial Water Quality Objectives (PWQO).

NITRITE

Nitrite (NO_2^-) is produced naturally as part of the process of converting ammonium into nitrate. It seldom accumulates in the soil, since the conversion from nitrite to nitrate is generally much faster than the conversion from ammonium to nitrite. Nitrite moves much like nitrate in the soil and groundwater zones.

The Ontario Drinking Water Standards (ODWS) set 1 mg/L (1 part per million) nitrite as nitrogen (NO_2-N) as the maximum level for drinking water in Ontario. Nitrite levels in drinking water should not exceed this value. The Canadian guideline for aquatic water quality has an upper limit for nitrite of 0.06 mg/L (60 µg/L or parts per billion). While nitrite is much more toxic to aquatic life than nitrate, nitrite tends to convert quickly to nitrate.

AMMONIA

Ammonium (NH_4^+) bonds to negatively charged surfaces of soil particles — clay in particular. The concentration of ammonium in the soil is generally quite low (<1 mg/kg), because it is quickly converted to nitrate under conditions that are favourable for mineralization. The exception is where high rates of an ammonium fertilizer (anhydrous ammonia, urea or ammonium sulphate) or high rates of manure are applied. Occasionally, heavy rainfall washes this concentrated ammonium from the field into surface water. A small part of this ammonium can be converted to dissolved un-ionized ammonia (NH_3), which can harm fish. The conditions that favour ammonia generation are alkaline pH and warm water temperatures.

Unlike nitrate and nitrite, ammonia is not a human health concern in drinking water at the levels typically observed in the natural environment. However, it is toxic to fish at high enough concentrations. The Provincial Water Quality Objective (PWQO) for dissolved un-ionized ammonia is 20 µg/L.

NATURAL LOSSES FROM THE NITROGEN CYCLE

Natural losses of nitrogen, in addition to nitrate leaching, occur through ammonia volatilization and denitrification. Ammonia volatilization occurs when manure or an ammonia-based fertilizer (particularly urea) are applied to the surface of the soil without mixing them into the soil. Over half of the ammonium N from manure can be lost to the air under warm, dry conditions, greatly reducing the fertilizer value of the manure. However, the concentrations of ammonia released are not high enough to cause direct environmental or human health harm outdoors, and most of the ammonia is re-deposited within a few hundred metres of where it was released. Ammonia concentrations can accumulate to toxic levels in confined areas such as barns or manure storages. There are concerns that some of this ammonia could contribute to the production of fine particulates, causing a decline in air quality.

Denitrification is a natural process where microbes in the rooting zone use the oxygen in nitrate where there is not enough air in the soil. This process converts the nitrate into gaseous forms of nitrogen — primarily N_2, but also into nitrous oxide (N_2O) or nitric oxide (NO). Conditions that favour dentrification within the rooting zone are soils with slow internal drainage (fine textured soils), an ample carbon supply (food for the microbes) and saturated soils from shallow groundwater or heavy rainfall. Denitrification can also occur in the groundwater and surface water environments (see Figure 1). In some aquifers, denitrification can result in the complete conversion of nitrate to dissolved nitrogen gas, which is not harmful to aquatic ecosystems or human health. However, denitrification cannot be counted on to eliminate all the nitrogen leaching to groundwater or running off to surface water.

FARM MANAGEMENT OPTIONS

When nitrogen leaves the root zone, it can affect the quality of groundwater and surface water. The key to reducing this is practising efficient on-farm management of nitrogen, so that as much of the available nitrogen as possible is used to grow crops and livestock and maintain soil health. The range of management options available to a producer varies depending on the farm's characteristics. These can be identified through the preparation of a nutrient management plan. The following sections describe some general approaches and specific ways to reduce the movement of nitrate to groundwater or the movement of ammonia to surface water.

Reduce total nitrogen loading

- Ensure livestock feed rations are not any higher than necessary to meet production targets. This will save both feed costs and excess nitrogen loss in the manure.
- Use nitrogen from sources available on the farm first, where possible (e.g., manure), before buying any nitrogen sources produced off-farm.

Prevent runoff from manure or other nutrient materials

- Store manure properly until it is ready for land application. Be sure your storage area is properly sited, designed and sized.

Manage fields to avoid excess nitrate that could leach to groundwater

- Identify fields and areas sensitive to nitrogen in areas where nutrient applications are planned. For instance, sandy or gravelly soils, and soils with shallow water tables are more susceptible to nitrogen leaching.
- Match nitrogen applications with crop requirements. Use the spring or pre-sidedress soil nitrogen test where available (e.g., for corn and barley).
- In your Nutrient Management Plan, account for nitrogen contributions from green manure crops and any previous crop rotations.
- In your Nutrient Management Plan, account for nitrogen from any manure or biosolid application.
- Apply most of the nitrogen just before the time of maximum crop uptake (e.g., sidedress corn).
- Split applications of nitrogen through techniques such as fertigation.
- Practise crop rotations to make efficient use of nitrogen and maintain healthy soils.
- Establish cover crops as needed to "tie up" any excess nitrogen at the end of the season.

Manage nutrient application to avoid ammonium losses to surface water

- Practice timely tillage to incorporate manure, balancing the risk of soil compaction with the losses of nitrogen to the atmosphere if the manure is not incorporated quickly.
- Avoid applying manure near surface water or on steeply sloping land.
- Keep application rates low enough to prevent runoff.
- Mix manure into the soil as soon possible after applying it.
- On tile-drained land, keep application rates of liquid manure below 40 m^3/ha (3,600 gal/ac) or pre-till the field before applying it. This will help prevent the movement of manure directly to tile through cracks or earthworm channels.
- Use buffer strips and erosion control structures to filter runoff before it enters surface water. Buffer strips in riparian zones have proven to reduce nutrient movement off the field into nearby surface water sources. Buffer strips consume excess nutrients before they flow into surface water and enhance opportunities for groundwater denitrification. See Figure 2, below, and the Best Management Practices publication, *Buffer Strips,* BMP 15, for a more detailed understanding of riparian zones.

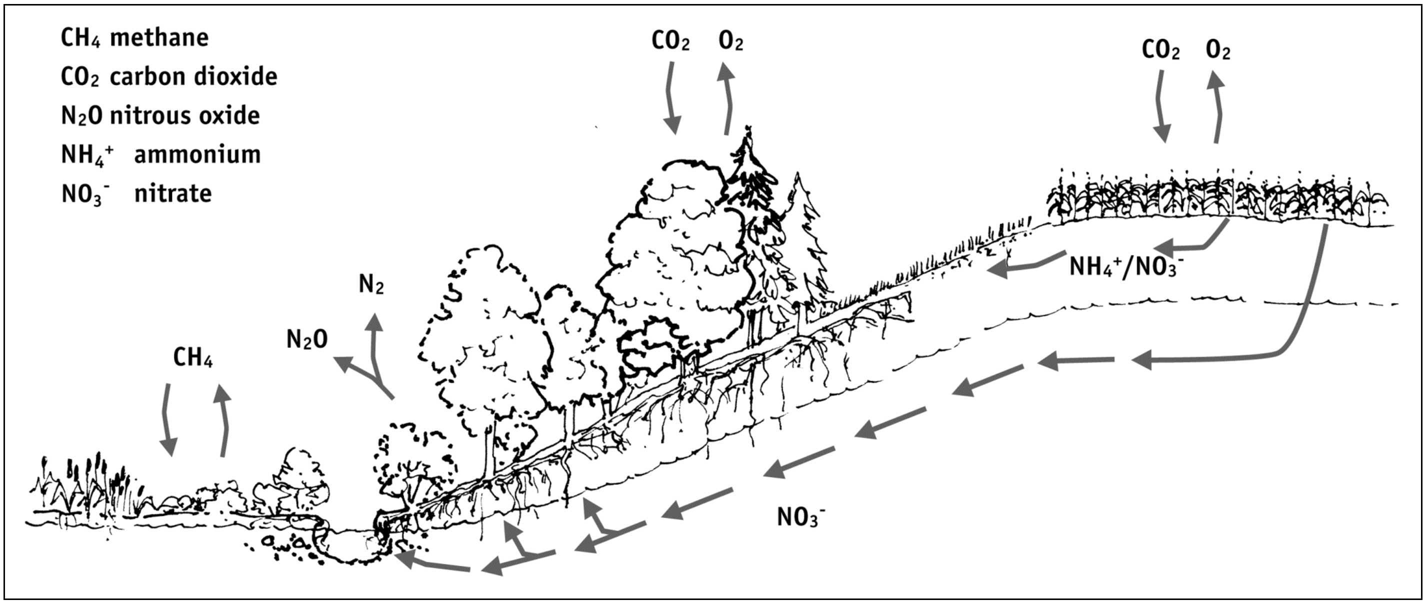

Figure 2: Buffer strips reduce nutrient movement by consuming excess nutrients before they flow into surface water and enhancing groundwater denitrification.

ONTARIO'S NITROGEN INDEX: PART OF ONTARIO'S NUTRIENT MANAGEMENT PLANNING SOFTWARE

The Nutrient Management Planning Software (NMAN) was developed to help farm operators prepare nutrient management plans. NMAN includes a feature called the Nitrogen Index (N-Index), which can help a producer evaluate the potential for nitrate leaching with a planned crop production practice. N-MAN uses soil profile characteristics to assess the potential for nitrate leaching from the field. The N-Index can evaluate the effect of manure type as well as the timing and rate of manure application on leaching. Crop nutrient balances calculated by NMAN also help determine the efficiency of the nitrogen applied to the field. For more information about nitrogen management, see the following Best Management Practices publications:

- Nutrient Management, BMP 05
- Nutrient Management Planning, BMP 14
- Buffer Strips, BMP 15

The key for managing nitrogen sources, including livestock manure and crop nutrients, is being as efficient as possible. An important part of this process is to ensure that you use farm management practices that account for the capacity of soils and the crops being grown to remove nitrogen. This will help ensure the sustainability and future uses of Ontario's water resources.

For additional information, visit the OMAFRA website at www.omafra.gov.on.ca or call 1-888-466-2372.

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